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and Studies of W Asymmetry
at the Tevatron Collider**

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LIMITS ON QUARK-LEPTON COMPOSITENESS AND STUDIES OF W ASYMMETRY AT THE TEVATRON COLLIDER

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Drell-Yan dilepton production at high invariant mass place strong limits on quark substructure. Compositeness limits from CDF Run 1, and expected sensitivity in Run II and TEV33 are presented. The W asymmetry data constrains the slope of the d/u quark distributions and significantly reduces the systematic error on the extracted value of the W mass.

1 W Charge Asymmetry, W mass, and the Slope of d/u

W^+ (W^-) bosons are produced in $p\bar{p}$ collisions primarily by the annihilation of u (d) quarks from the proton and \bar{d} (\bar{u}) quarks from the antiproton. Because the u quark tends to carry a larger fraction of the proton's momentum than the d quark the W^+ (W^-) tends to be boosted in the proton (antiproton) direction. The charge asymmetry in the production of W's, as a function of rapidity, is therefore related to the difference in the quark distributions at very high Q^2 ($\approx M_W^2$) and low x ($0.007 < x < 0.24$). The asymmetry is sensitive to the ratio of d and u quark distributions to $x < 0.01$ at $Q^2 \approx M_W^2$, where nonperturbative effects are minimal.

In the most recent measurement by CDF, the dataset used in the W lepton charge asymmetry analysis has been significantly increased. First, data from Run 1B (94/95) corresponding to an additional 91 pb^{-1} of integrated luminosity has been added to the 20 pb^{-1} which has been previously published¹. Secondly, the data sample in the forward pseudo-rapidity region between 1.2 to 1.8 has been doubled, and extended to higher values of η . This was accomplished by including, in addition to events for which charge of the electron is measured using the standard central tracking information, events in the forward direction for which the electron charge was measured using a combination of stand-alone silicon SVX track finder in conjunction with a shower cluster centroid position from the strips and pads in the plug electromagnetic calorimeter. In addition, data from the forward muon detector have been included.

In CDF, positively charged particles are bent in the increasing ϕ direction, and negatively charged particles are bent in the decreasing ϕ directions. Thus the charge of electrons can then be determined by comparing the ϕ_{SVX} measured with Silicon Vertex Detector, with ϕ_{PEM} measured with the Plug Electromagnetic Strips.

These new preliminary W charge asymmetry results are compared with theoretical predictions of various parton distribution functions^{2,3} (PDFs) using a NLO calculation⁶ in Figure 1. The reduced statistical errors have greatly increased the differentiating power between modern PDFs. However, there are differences between the NLO theory and that data in the forward direction, and indicate the need for further tuning of the d/u ratio at smaller value of x . Note that the difference between data and theory in the forward direction becomes even worse when a resummation⁷ calculation is used. Figure 2. shows a comparison of the data with the predictions of the MRSA parton distribution² using both the NLO and the resummed calculations. A comparison between data and the resummation calculation for all structure functions is currently being performed.

By restricting the shape of PDF's, the W asymmetry measurement has significantly reduced the systematic uncertainty in the W mass measurement. The fitted W mass is strongly correlated with the W charge asymmetry. The CDF results for the W asymmetry from the Run 1A data¹ have been used as a guide in determining the uncertainty due to the PDF's. Fig. 3 shows the correlation between the ΔM_W (in MeV) and $\Delta\sigma_{A(\eta)}$, the deviation between average measured asymmetry for the new data and the NLO PDF

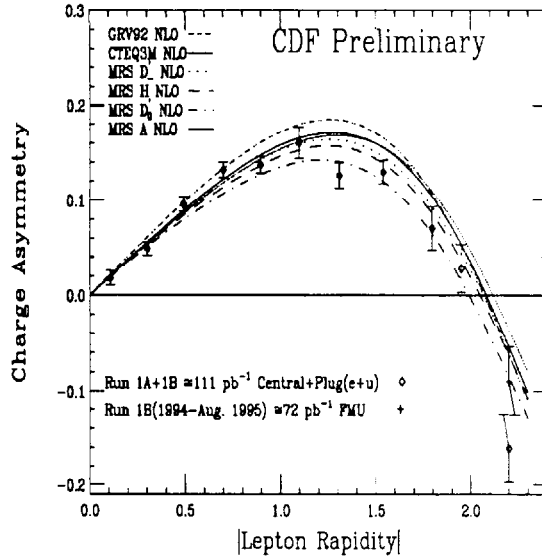


Figure 1: Comparisons of W asymmetry measurement with Recent PDF's Predictions. The charge asymmetry measured by CDF, compared to predictions of the latest PDF's (using NLO DYRAD). The data includes the Run 1A Central and Plug data sets (PRL, 74 (1995)) and additionally the Run 1B Central+Plug data set (CDF Preliminary).

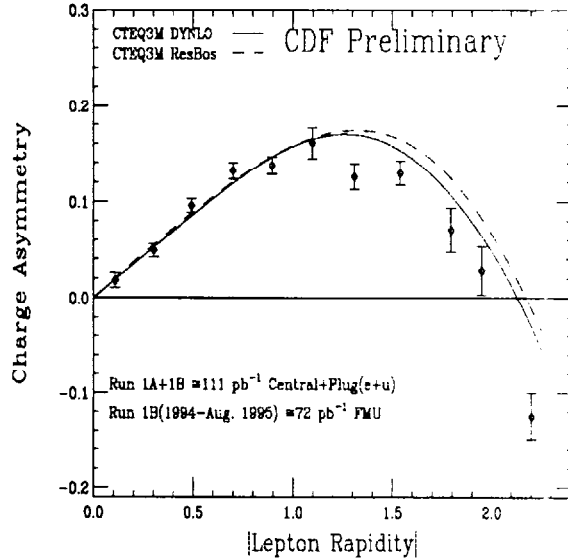


Figure 2: Comparisons of W asymmetry measurement with two theories using the same parton distributions. Shown are the theoretical curves using the NLO (DYRAD) calculation and also the Resummation (RESBOS).

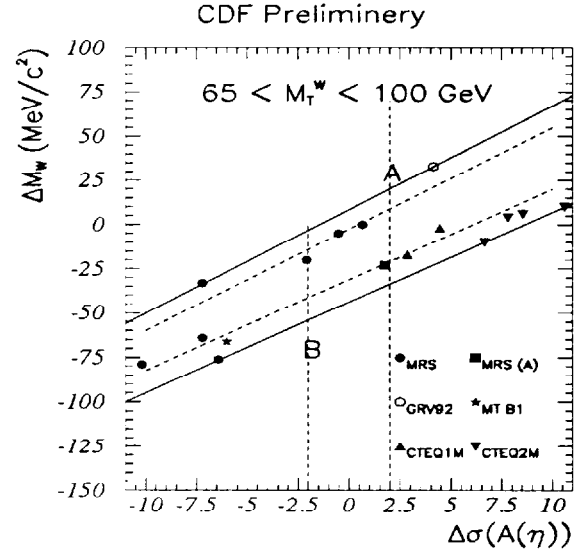


Figure 3: The correlation between the ΔM_W (in MeV) and $\xi = \Delta\sigma_{A(\eta)}$, the deviation between average measured asymmetry and the PDF predictions. The M_T^W regions for the W mass fitting is $65 < M_T^W < 100$ GeV. The area between solid lines covers all the points and the dashed lines denote $\pm 2 \Delta\sigma_{A(\eta)}$. The W mass measurement uncertainty due to PDF's is taken to be half of the two extreme values in the area within $\pm 2 \Delta\sigma_{A(\eta)}$. This analysis was performed using the DYRAD NLO calculation. The data sample includes all central and forward 1A and 1B electron and muon W events.

predictions (a comparison using the resummation calculation is currently being done). The W mass extracted from the run 1A data is 80.41 ± 0.18 GeV from the combined electron and muon data. The previously asymmetry measurement allowed the CDF to reduce systematic uncertainty on M_W due to PDF's to 50 MeV for Run 1A. This error has been included in the overall 180 MeV error for run 1A. As shown in Fig. 3 the new asymmetry data presented here indicates that a greater reduction in the error from uncertainties in PDF's is possible. This is important because smaller statistical and systematic errors on the W mass are expected when the W mass analysis of the run 1B data sample is completed.

2 High Mass Drell Yan and limits on quark substructure

The Drell-Yan events are easily reconstructed from the measured properties of the decay lep-

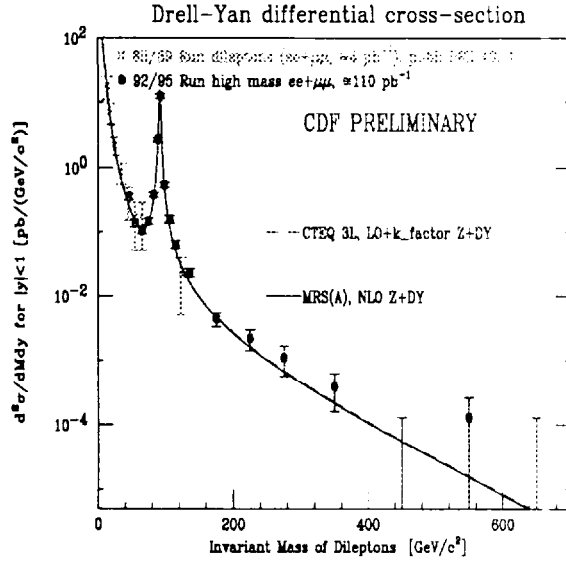


Figure 4: Drell-Yan dielectron+dimuon combined (dark circle symbols) pair production cross section from Run 1A+1B corresponding to $108 \pm 7.1 \text{ pb}^{-1}$ of data. For comparison we also show results from Run 88/89. At high mass, both the NLO and LO+Kfactor QCD calculations agrees with the data.

tions. The differential Drell-Yan cross section provides information on the magnitude of the quark distributions in the x range 0.006-0.03 over a Q^2 range of 121-3600 GeV^2 . The CDF experiment has measured ⁴ the differential cross section $d^2\sigma/dMdy_{|y|<1}$, over the mass range $11 < M < 150 \text{ GeV}/c^2$ using dielectron and dimuon data from 1988-89 collider run ($\approx 4 \text{ pb}^{-1}$). The results showed $1/M^3$ dependence as is expected from naive Drell-Yan model. The measurement favored those distributions which have the largest quark contribution in the x interval 0.006 to 0.03, in particular the sets which used the most recent DIS data. However, as was the case for the 1988-89 W asymmetry data, the statistics were limited.

Recently, CDF has presented a preliminary measurement of the Drell-Yan cross-section using the combined Run 92/93 and 94/95 data corresponding to the total integrated luminosity of 110 pb^{-1} . Figure 4 shows results of the combined dielectron and dimuon Drell-Yan cross-section measurement using high mass events collected during Run 1A+1B. The data is consistent with the earlier published Drell-Yan measurement by CDF ⁴ and agrees well with the NLO calculations.

The measurement of the dilepton invariant

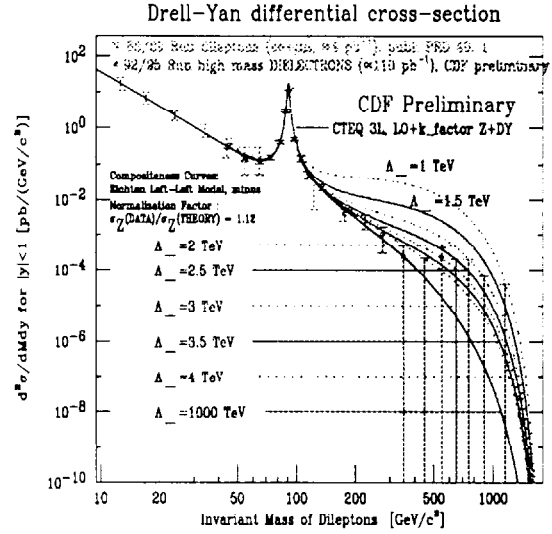


Figure 5: Comparison between the CDF Drell-Yan cross-section measurement and theoretical prediction for various values of compositeness scale $\Lambda_{LL}^-(ee)$, for dielectron channel.

mass spectrum is also sensitive to the possible existence of an additional contact term interaction between quarks and leptons characterized by the compositeness scale Λ . If quarks and leptons are composite particles that share constituents, an effective contact interaction arises between them ⁵. This interaction would result in an enhancement of the dilepton differential cross section at high invariant mass. Earlier ⁸ CDF 95% CL limits on the scale of such an effective contact interaction were extracted from the 88/89 dataset. The limits (on contact terms for $qq-\mu\mu, qq-ee$ interactions) were extracted for the Eichten's Left-Left (LL) model. In this model - (+) corresponds to constructive (destructive) interference with the photon amplitude and Λ_{LL} refers to the scale parametrizing the interaction between left-handed currents.

CDF has new preliminary limits on the compositeness scale Λ . The analysis was performed using the observed dilepton events with mass above 150 GeV and the bin likelihood technique. Figure 5 and show comparison between the Drell-Yan cross-section measurement and theoretical predictions for various values of compositeness scale $\Lambda_{LL}^-(ee)$. The 95% CL limits (on contact terms for $qq-\mu\mu, qq-ee$ interactions) based on the absence of high mass dilepton events in the $\approx 110 \text{ pb}^{-1}$ of data are shown below.

$$\Lambda_{LL}^-(ee) \geq 3.4 \text{ TeV}(CDF/110pb^{-1}), \quad (1)$$

$$\Lambda_{LL}^+(ee) \geq 2.4 \text{ TeV}(CDF/110pb^{-1}), \quad (2)$$

$$\Lambda_{LL}^-(\mu\mu) \geq 3.5 \text{ TeV}(CDF/110pb^{-1}), \quad (3)$$

$$\Lambda_{LL}^+(\mu\mu) \geq 2.9 \text{ TeV}(CDF/110pb^{-1}). \quad (4)$$

The process $u\bar{u}$ and $d\bar{d}$ going to quarks, or to dimuons or dielectrons may have different compositeness scales. If one assumes that the scales are the same for electrons and muons, the combined CDF electron and muon data yield compositeness scale limits of $\Lambda_{LL}^-(ll)$ are:

$$\Lambda_{LL}^-(ll) \geq 3.8 \text{ TeV}(CDF/110pb^{-1}), \quad (5)$$

$$\Lambda_{LL}^+(ll) \geq 2.9 \text{ TeV}(CDF/110pb^{-1}). \quad (6)$$

Results for other models (e.g. LR+, LR-, RL+, RL-, RR+ and RR-, and scalar) are currently being extracted from the CDF data.

The CCFR/NuTeV Collaboration has presented the 95% CL limits on compositeness scale ($\nu\nu - qq$ contact term interaction) at this conference⁹. These limits are:

$$\Lambda_{LL}^-(\nu_\mu\nu_\mu) \geq 3.5 \text{ TeV}(CCFR/NuTeV), \quad (7)$$

$$\Lambda_{LL}^+(\nu_\mu\nu_\mu) \geq 3.8 \text{ TeV}(CCFR/NuTeV). \quad (8)$$

In this conference, the HERA groups (ZEUS and H1) have also presented limits on compositeness.

$$\Lambda_{LL}^-(ee) \geq 1.0 \text{ TeV}(ZEUS), 1.0 \text{ TeV}(H1), \quad (9)$$

$$\Lambda_{LL}^+(ee) \geq 2.0 \text{ TeV}(ZEUS), 2.3 \text{ TeV}(H1), \quad (10)$$

3 High Mass Drell Yan and limits on Z' bosons

Preliminary results on Z' mass limit using the CDF Run 1A+1B data have been recently presented at 1996 APS Meeting. Combining both dielectron and dimuon channels using Run 1A+1B, CDF set a Z' lower mass limit of 690 GeV/ c^2 . CDF also set limits for the production of sequential neutral vector bosons within the framework of E_6 superstring inspired supersymmetric models. The CDF mass limits at the 95% CL for a variety of models range from 550 GeV to 620 GeV, when supersymmetric and exotic decays of the Z' are not considered.

4 Expected Limits in Run II and TeV 33.

The Tevatron Collider 1999-2000 run (Run II) is expected to accumulate a total of 2 fb⁻¹ of integrated luminosity. In addition, Fermilab is investigating the possibility of accelerator improvements that can yield data samples with 10-30 fb⁻¹ of integrated luminosity (TeV33). Studies¹⁰ at the 1996 Snowmass workshop using Monte Carlo generated events (for 100 Gedanken experiments) indicate that using the maximum likelihood method, the expected sensitivities to compositeness scale Λ are:

$$\Lambda_{LL}^-(ee) \geq 10 \text{ TeV}(RunII, 2fb^{-1}), \quad (11)$$

$$\Lambda_{LL}^+(ee) \geq 6.5 \text{ TeV}(RunII, 2fb^{-1}). \quad (12)$$

$$\Lambda_{LL}^-(ee) \geq 20 \text{ TeV}(TeV33, 30fb^{-1}), \quad (13)$$

$$\Lambda_{LL}^+(ee) \geq 14 \text{ TeV}(TeV33, 30fb^{-1}). \quad (14)$$

Similarly, with 2 fb⁻¹ of data, sensitivity to Z' mass of 1.0-1.1 TeV is expected.

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